N84-22891

NASA Technical Memorandum 83652

Advances in Solid State Switchgear Technology for Large Space Power Systems

Gale R. Sundberg
Lewis Research Center
Cleveland, Ohio

Prepared for the
Nineteenth Intersociety Energy Conversion Engineering Conference
cosponsored by the ANS, ASME, SAE, IEEE, AIAA, ACS, and AIChE
San Francisco, California, August 19-24, 1984

NASA

ADVANCES IN SOLID STATE SWITCHGEAR TECHNOLOGY FOR LARGE SPACE POWER SYSTEMS

Gale R. Sundberg

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

E-2096-1

SUMMARY

NASA's Lewis Research Center has systemmatically pushed the development of high voltage solid state remote power controllers (RPC's) and the required semiconductor power switches to provide baseline technology for large, high power distribution systems in the Space Station, All Electric Airplane and other advanced aerospace applications. The technology of solid state RPC's has progressed from the development to the application stage at various voltage and power levels from a few hundred watts to 50 kWs. RPC's have been or are being developed for dc voltages from 28 to 1200 V and ac voltages of 115, 230, and 440 V at frequencies of 400 Hz to 20 kHz.

This paper reviews the benefits and operation of solid state RPC's, and highlights several developments of NASA Lewis and other Government agencies to bring the RPC to technology readiness for future aerospace needs. New technology programs to develop a new family of $(DI)^2$ semiconductor switches and 20 kHz, 440 V ac RPC's are also described.

INTRODUCTION

With the emergence of the Space Shuttle as an operational part of NASA's Space Transportation System, we are entering a new era of large, high power spacecraft. As the spacecraft grow in size and complexity, so will the electrical power level and the transmission distances from source to load. Within the next decade spacecraft missions may require electrical power levels up to 50 kW or more in orbits from low earth (LEO) to geosynchronous (GEO). This growth will require dramatic changes in the generation, management and distribution of the electrical power.

As system power levels increase beyond today's low kW level, the system voltage must also increase to avoid excessive weight and power losses in current carrying cables. Many studies have shown that great advantages accrue when these larger power systems are operated at voltages higher than the conventional 28 V dc and/or 115 V ac. Savings in power distribution system weight and I^2R losses of 25 to 50% with system voltages raised to 300 V (dc or ac) have been projected for large spacecraft (of the Space Shuttle size), Space Stations and various types of large aircraft (refs. 1 and 2).

While the verdict has not been reached as to whether ac or dc distribution is better at the higher voltages, power systems continue to grow in power demand and size. And, technical efforts continue to reduce system complexity, shorten power bus runs, and decrease the number of switching operations. Therefore, various multiplexed data bus systems with computer control of the transmission and distribution system are being investigated.

Critical to the realization of such power distribution systems, however, is the availability of solid state power controllers (RPC's), which provide remote on-off switching, overcurrent protection, efficient operation, and maintain total system power quality. Solid state RPC's provide well-defined, standard interfaces between power sources and loads for large, high voltage power systems. In addition they are compatible with multiplexed data bus power management and control interfaces required for the larger power systems with a potential for multiple users. In anticipation of this need, considerable effort has been concentrated by the NASA Lewis Research Center on the development of solid state RPC's that can be used for increased voltage dc and ac power distribution systems (ref. 3).

The purpose of this paper is to describe the advances in solid state switch gear technology over the past ten years and highlight some of the emerging semiconductor developments that will enable further advances. The paper will also focus on some projected applications in large electrical power systems for the Space Station, for future megawatt level power systems in space (under study) and for large all electric airplanes being developed for both commercial and military aviation.

BENEFITS OF RPC's

RPC's are solid state devices that combine in one unit the capability to perform all the needed functions of load switching, overload protection and a direct indication of whether the load is ON or OFF. They provide total system protection of equipment and wiring. RPC's are designed to be located near the load and communicate control and status information remotely via low level signals of a few milliwatts or light impulses through fiber optics. In addition, solid state RPC's possess several advantages that contribute directly to power system improvements. The advantages include:

- "Contactless" switching (no contact bounce, wear or arcing)
- Controlled rates of current rise and fall
- System isolation from load transients
- Fast, precise, repeatable trip-out response
- Wide operating temperature range (-55° to 100° C)
- Compatibility with all power sources, load types and computer control
- Electrical isolation and control/status signals from power bus
- Solid state reliability and ruggedness to vibration and shock

Figure 1 shows a basic RPC in a typical application. Many of the outstanding features of NASA Lewis developed solid state RPC's are summarized in figure 2.

Internal dI/dt limiting inherent in the drive circuitry of solid state RPC's provide essentially infinite surge capability without bulky inductors. This feature insures compatibility with most power sources and leads to compact, hybrid circuit packaging. Another feature of benefit to the power system is the demonstrated capability to meet requirements for EMI generation and susceptibility.

The capability of the solid state RPC's to provide superior control of load currents leads directly to reduced power system transients and improves power quality. The improved power quality reduces size and weight and increases reliability of power distribution equipment and loads. Smaller power sources, greater system manageability, and positive fault isolation are the result. This in turn will lead to improved compatibility among developers of large spacecraft and potential users irrespective of the type of electrical distribution system or the technical requirements of the load.

OPERATION AND DESIGN OF RPC'S

This section will describe some of the basic features of an RPC and its critical components that lead to its above mentioned benefits. Since the main functions of an RPC are to turn loads ON and OFF and protect system interfaces and wires, a short description of its operation will be given, also.

In the normal OFF state of an RPC the control voltage is zero and all internal circuits are powered down. With bus voltage present on the power input, the RPC is turned ON in a load circuit when a positive control voltage is applied to the control input. Figure 3 is a block diagram of a typical RPC showing the basic functions. To insure isolation the control signal is usually optically coupled to the RPC logic circuits and to an internal power supply that converts bus voltage to low voltage for power to the logic circuits. (This low voltage may be supplied externally in a large system, however, with one redundant logic supply furnishing power to several RPC logic circuits.) With the TRIP and LATCH circuit and the AND and OR gates armed, the SWITCH DRIVER is then activated to turn-on the main POWER SWITCH and energize the load in a controlled manner.

When load current is flowing to the load, the RPC sends back an ON signal for STATUS indication. The magnitude of the load current is sensed by the CURRENT SENSOR. In the event of a fault or overload condition the CURRENT SENSOR compares the current to a reference and takes appropriate action. Depending on the capability of the RPC it may limit the current or integrate it for a time and remain ON if the overload is transient or short-term in nature. If the overload is large or long-term, the RPC removes drive to the POWER SWITCH, de-energizes the load, sends a TRIPPED status signal, and shuts down all internal circuits except CONTROL/STATUS.

Figure 4 summarizes several types of overcurrent protection typically used in RPC's. The RPC can be turned on again by applying another ON signal after a preset time delay. Obviously the whole ON/OFF/TRIPPED control/status sequence may be software programmed and controlled via an onboard computer or microprocessor in a large spacecraft or aircraft power system.

Power Switch

The greatest design challenge in the solid state RPC is the power switch with its associated drive, trip and isolation circuitry. The power switch must maintain complete control of current to the load under all possible conditions, i.e., turn-on, turn-off and fault conditions. For worst case

(shorted load) the switch must handle power equal to maximum voltage times maximum allowable current for a time corresponding to its trip curve. In addition the switch must be capable of changing quickly from blocking to conducting and back again without passing transitional current spikes that would damage the wiring harness, other equipment in the electrical system, or the RPC itself.

Power Transistors and Diodes

Because of their superior control capabilities under all load conditions, fast switching speeds and low forward voltage drop, bipolar transistors, Darlington transistors or some form of MOSFET'S are generally most desirable for dc RPC's. For ac RPC's at lower frequencies thyristors, especially gate turn-off (GTO) thyristors may also be desirable. Higher frequency ac systems now under study are just beginning to identify the best switches, but some form of transistor appears to be preferable.

Over the past ten years NASA Lewis has undertaken the technology development for high voltage, high power, high frequency bipolar transistors and fast recovery diodes for space power and aircraft applications. Results to date from this program have been a family of high frequency, power transistors and diodes that have enabled solid state RPC's up to 1000 V dc and 25 kW power capability to be built. Summaries of this work are given in references 4 and 5, and shown in tables I and II.

New Semiconductor Developments

A new family of semiconductor devices based on a radical departure from conventional p-n junction technology has been supported by NASA Lewis over the past 10 years at the University of Cincinnati. These new semiconductors have the potential to raise the switching voltage a factor of ten higher than p-n junction devices while exhibiting extremely low (or zero) forward voltage (ref. 4). Figure 5 illustrates the possibilities based on early theoretical studies, but confirmed by actual experimental data as shown.

The new Double Injection, Deep Impurity $(DI)^2$ semiconductor switches depend on the trapping characteristics of compensated deep impurities near the midpoint of the energy bandgap in a bulk semiconductor under double charge injection at the electrodes. Recent studies of gating phenomenon give evidence for many potential circuit applications for the $(DI)^2$ switch because of its thyristor-like switching characteristics (ref. 6). Figure 6 shows a generalized volt-ampere characteristic curve showing the switching effects using two types of gates. The cathode gate (a MOS type) alters the threshold level and the injection gate modifies the holding voltage either pushing it toward zero or to higher voltage to assist turn-off depending on gate polarity. Thus, high voltage, very low forward drop, opening switches appear feasible. At present, work is underway to develop $(DI)^2$ devices capable of blocking 1 to 10 kV and handling 1 to 10 A at the Westinghouse R&D Center sponsored by NASA Lewis. Manufacturing feasibility of a 1600 V, 1.5 A $(DI)^2$ switch was recently demonstrated (ref. 7). Solid state switchgear using such devices rather than conventional semiconductors may be much more efficient, more versatile in spacecraft applications, and, much smaller and lighter weight.

TODAY'S RPC TECHNOLOGY

Solid state RPC development efforts have been carried out over the past ten years at a number of voltages for both dc and ac electrical power systems. Several 28 V dc and 115 V ac RPC's have been fully developed and are operational. The Space Shuttle, for example, uses about 600 solid state RPC's in six ratings from 3 to 20 A at 28 V dc. RPC's for 115 V ac are available in single and three phase units for currents in the range of 10 to 100 A at 400 Hz.

While other Government agencies have demonstrated 230 V ac controllers for various current levels at 400 Hz, NASA Lewis has systemmatically pushed the development of dc solid state RPC's up to 1200 V with current levels to 100 A at lower voltages. Specific developments have focussed at 120, 300, 400, 800, 1000, and 1200 V dc. Flight qualifiable units at 5 and 30 A are available at 120 V dc. Breadboard and engineering model RPC's have been built and tested at 300 V dc that handle currents of 1, 2, 50 and 80 A. One high current circuitbreaker at 300 V dc also incorporates an electromechanical contactor with solid state arc suppression to give very low forward voltage drop.

In addition to the contractor developments described above, NASA Lewis undertook an in-house investigation to develop several advanced RPC designs using relatively new MOSFET's and gate turn-off (GTO) thyristors as the main power switches (ref. 8). Seven RPC's were built and tested using the two basic switch types. Four GTO-RPC's for power levels of 7.8 to 52 kW and voltages of 800 to 1200 V dc were designed. In addition three power MOSFET-RPC's in power levels from 8 to 15 kW and voltages ranging from 150 to 800 V dc were successfully demonstrated. Several of these units are currently being tested in the NASA Lewis 30 kW Space Station Test Bed.

In the following sections several of the key RPC developments will be summarized along with a new initiative RPC for a high voltage, high frequency distribution system. Table III summarizes NASA sponsored RPC development to date.

28 V dc RPC

The Space Shuttle RPC's in six current ratings from 3 to 20 A are designed to operate from a nominal 28 V dc generated by fuel cells (ref. 9). The six ratings are constructed in three package sizes in a hybrid microelectronic configuration and encased in hermetically sealed bolt down packages with stud-type terminal posts. Figure 7 shows a cut-away drawing of the Shuttle RPC. These RPC's feature current limiting with controlled turn-on and turn-off rates. A special drive circuit responsive to load current reduces power dissipation especially at partial loads.

Of special interest is the fact that these RPC's are 4 terminal devices. The use of a common ground for power and control precludes an isolation interface between the control and power circuits. Status indication is not provided by the RPC itself. However, load volt-input/output interfaces are provided for the computer. Reference 9 discusses the RPC design, evaluation and results in considerable detail.

These RPC's have amassed an outstanding record of reliability and proven performance in the Space Shuttle electrical distribution system. They have not failed in flight! Throughout all orbital missions and during all suborbital and ground tests, they have performed flawlessly. Estimates of total unit operating times without a failure are approaching 50 million hours (ref. 10). These estimates do include, however, pre- and post-flight ground tests along with many hours of suborbital and simulator testing of the RPC's.

120 V dc RPC

Of significance for 120 V dc applications is the development of three types of RPC's at two current ratings of 5 and 30 A. All three types have a coordination of trip characteristics to permit series/parallel operation of the RPC's in a distribution system. They control and distribute power at 600 watt and 3.6 kW levels with demonstrated efficiencies of 98.5 to 99.0 percent at rated loads.

Hybrid versions of all three types have been manufactured and fully tested. They are hermetically sealed and fully capable of flight applications in space. Figure 8 is a cutaway of a 120 V dc RPC with current limiting. The package sizes range from 4.4 x 4.7 x 2.0 cm high weighing 100 grams for Type 1 to 5.5 x 7.1 x 1.9 cm high weighing 203 grams for the Type III (refs. 11 and 12). Reference 3 also summarizes this RPC.

270/300 V dc RPC

As an extension of the 120 V dc RPC's two types of working RPC breadboards at one and two ampere current ratings were build and tested for 270/300 V dc. Both types have I^2t overload protection. The 1 A RPC, however, has current limiting of the form shown in figure 4(c). These RPC's have greater than 99 percent efficiency, controlled rise and fall times, use a Darlington NPN power switch and are compatible with both a current sinking and a SOSTEL type control/status indication (refs. 13 and 14).

230 V ac/400 Hz RPC

Flightworthy prototypes of power controllers rated at 1.5 A and 230 V 400 Hz for use on the B-1 aircraft electrical load distribution system have been built and evaluated. The RPC's were designed to interface with the Electric Multiplex (EMUX) control system under development by the Air Force (refs. 15 and 16). Two designs have been demonstrated, one using transistor switches and the other SCR's, which are competitive for ac applications using zero crossing turn-off. At the time of this writing, however, further development of the solid state RPC's has been suspended with no plans to retrofit them into the latest model B-1B aircraft.

High Power RPC's

With the new family of D6 and D7 size transistors available from NASA Lewis sponsored development, solid state RPC's at power levels up to the 25 kW range become possible (refs. 17 and 18). The D60T, a bipolar transistor rated at 500 V, 50 A has enabled dc RPC's at voltage levels of 200 to 400 V dc and 50 A to be

demonstrated (ref. 19). Figure 9 shows an engineering model of the 400 V, 50 A RPC and figure 10 shows the 400 V, 80 A hybrid electromechanical/solid state circuit breaker in assembly. Also, a 1200 V, 50 A bipolar transistor has enabled a 1000 V dc, 25 A RPC to be built (ref. 20).

During the development of the higher power RPC's various power switches were investigated. Several prototype units were designed and demonstrated using these switches. Table IV summarizes the RPC's developed showing voltage, current and power switch type. Noteworthy is the fact that excellent performance was demonstrated with four different types of power switches - thyristors, bipolar transistors, various combination of MOSFET's and the hybrid electromechanical/semiconductor switch.

As the newer types of semiconductor switches became available, namely MOSFET's and GTO's, additional advancements were made in RPC technology (ref. 21). The Lewis Research Center has demonstrated a family of seven RPC's based on these new switches. The new RPC's span the power range from 7.8 to 52 kW at voltage levels from 150 to 1200 V dc. As shown in figure 11 these advanced RPC's demonstrate voltage and power increases over the original Shuttle RPC's of up to 80 times while decreasing the percentage power loss by a factor of four. Additionally, they feature programmable overcurrent tripouts and the capability to be fabricated in small, lightweight packages.

440 V ac, 20 kHz RPC

Preliminary All Electric Airplane studies have identified significant advantages, e. g., a 10 percent reduction in total aircraft weight and direct operating costs, for a large airplane using a high frequency ac power distribution system. The major benefits result from savings particularly with regard to the motor control system required for aircraft engine starting and for flight control surfaces.

In addition to lower weight and more efficient motor drives, however, another important advantage of 20 kHz sinusoidal power distribution is the expected ease of current limiting and fault protection. Since the current is "commutated" inherently, switching devices do not have to interrupt high currents. Also, since energy per cycle is low, protective devices will not require high rupture capacity. Therefore, remote power controllers for 20 kHz distribution systems are anticipated to be small, simple and lightweight.

Development work is now underway to demonstrate remote bus isolators and selector switches in the form of RPC's to provide fault protection and load interrupt capability with a 20 kHz, 440 V ac, single phase, sinusoidal power distribution system. RPC's with current ratings of 5, 10, 25 and 50 A will be built and tested for system operation. The RPC's will be studied and configured to interface and operate in an advanced electrical secondary power system for commercial aircraft.

SUMMARY

The development of solid state RPC's has progressed from the development to the application stage at various voltage and power levels from a few hundred watts to over 50 kWs for aerospace distribution systems. This paper has reviewed benefits and operation of solid state RPC's, and highlighted

several developments of NASA Lewis and others to bring the RPC to technology readiness for future aerospace needs.

Through NASA and the DOD several 28 V dc and 115 V ac RPC's have been fully developed and are operational. In its 28 V dc distribution system the Space Shuttle uses over 600 solid state RPC's, which have performed flawlessly in all orbital missions and flight tests. RPC's for 115 V ac are available in single and three phase units for currents in the range of 10 to 100 A and 400 Hz distribution frequencies for aircraft distribution systems.

NASA Lewis has systemmatically pushed the development of high voltage dc RPC's and the required power switches to provide baseline technology for future large power distribution systems. With the new family of D7ST type transistors available, solid state RPC's have been built and tested at voltages of 120, 300, 400 V dc and currents to 100 A. Also, several units have been demonstrated at 800 to 1200 V dc and power levels up to 52 kWs using several types of power switches.

The development of advanced power handling devices are essential to the creation of large, high power electrical distribution systems. Therefore, NASA Lewis has an ongoing program to develop the specific components needed to meet the unique requirements of advanced aircraft and space power systems. The $(DI)^2$ semiconductor switches and the 20 kHz, 440 V ac remote bus isolators and power controllers are two examples of NASA's effort to satisfy the nations future technology needs.

CONCLUSIONS

Solid state remote power controllers have an important role to play not only in large space power systems such as the Space Station but also in future aircraft such as the All Electric Airplane. They provide well-defined, standard interfaces between power sources and loads in large, high voltage power distribution systems. And, they are compatible with the multiplexed data bus power management and control interfaces required for the larger power systems.

Although much work has already been done on solid state RPC's by NASA and others, much work needs to be done at the system integration level at the higher voltage and power levels. The basic technology for solid state remote power controllers, however, is ready to be applied to the next generation of both spacecraft and aircraft. We await the specific program initiative and the system definition to proceed.

REFERENCES

1. C. H. Lee, and C. Y. Chin, in <u>Power Conditioning Specialists Conference 1971 Record</u>, pp. 162-174, Institute of Electrical and Electronics Engineers, New York, (1971).

2. A. Krausz, and J. L. Felch, in <u>IEEE Power Processing and Electronics Specialists Conference 1972, Record</u>, pp. 183-193, Institute of Electrical and Electronics Engineers, New York, (1972).

3. G. R. Sundberg, and W. W. Billings, in PESC '77 Record: IEEE Power Electronics Specialists Conference -- 1977, pp. 244-253, Institute of Electrical and Electronics Engineers, New York, (1977).

4. R. C. Finke, and G. R. Sundberg, "Advanced Electrical Power System Technology for the All Electric Aircraft", NASA TM-83390 (1983); also in NAECON 1983, pp. 53-55, Institute of Electrical and Electronics Engineers, New York, (1983).

5. D. D. Renz, in 19th Intersociety Energy Conversion Engineering Conference, 1984, American Nuclear Society New York (1984).

6. H. T. Henderson, J. Asbrok, and A. Kapoor, in International Electron Devices Meeting, 1978, pp. 680-683, Institute of Electrical and Electronics Engineers, New York (1978).

7. F. A. Selim, and D. W. Whitson, "Double-Injection, Deep-Impurity Switch Development," NASA CR-168335, (83-9FS-DISQR-R1) Westinghouse R D Center (Dec. 1983).

8. J. C. Sturman, Private Communication (Mar. 1984).

9. D. A. Fox, "Remote Power Controllers for the NASA Space Shuttle Orbiter", AIAA Paper 77-494 (Mar. 1977).

10. J. Sullivan, Private Communication (Mar. 1984).

11. D. E. Baker, in Power Electronics Specialists Conference, pp. 151-160, Institute of Electrical and Electronics Engineers, New York, (1975).

12. G. R. Sundberg, and D. E. Baker, "Solid State Remote Power Controllers for 120 V dc Power Systems," NASA TM X-71874, (Apr. 1976).

13. W. W. Billings, and G. R. Sundberg, in Proceedings of the IEEE 1977 National Aerospace and Electronics Conference: NAECON '77, pp. 186-192, Institute of Electrical and Electronics Engineers, New York (1977).

14. W. W. Billings, "Aerospace Technology Development of Solid State Remote Power Controllers for 300 V dc with Current Ratings of One and Two Amperes, One Type Having Current Limiting," NASA CR-135199, (WAED 77-OIE) Westinghouse Electric Corporation Aerospace Electrical Division (June 1977).

15. E. Caputo, and D. G. Fox, "Future Trends in Air Force Aircraft Electrical Power Distribution and Control," AIAA Paper 77-493, (1977).

16. W. W. Billings, "AC Power Controllers for B-1 Flight Tests, Part 1: Final Technical Report Design, Development Fabrication and Testing of Hybrid Power Controllers," AFAPL-TR-75-68 Part 1, Westinghouse Electric Corporation, Aerospace Electrical Division (Sept. 1975).

17. P. L. Hower, "High-Current, Fast-Switching Transistor Development," Westinghouse R D Center NASA CR-165372, (DYD-10892-CE, 81-9F5-LTRAN-R1), (Mar 1981).

18. P. L. Hower, and Y. C. Kao, "High-Voltage Power-Transistor Development," NASA CR-165547, (CLD-11015-CE, 81-9FS-HTRAN-R5), Westinghouse Electric Corporation (Oct. 1981).

19. W. W. Billings, "High Voltage DC Switch-gear Development for Multi-kW Space Power Systems," NASA CR-165413, (WAED-81-05E), Westinghouse Electric Corporation, Electrical Systems Division, (Nov. 1981).

20. J. T. Mitchell, "Kilovolt DC Solid State Remote Power Controller Development, Final Report" NASA CR-168041, (WESLE-82-07E), Westinghouse Electric Corporation, Electrical Systems Division (Oct. 1982).

21. J. C. Sturman, "High Voltage, High Power Solid State, Remote Power Controllers for Aerospace Applications," to be published as a NASA Technical Publication.

TABLE I. – BI-POLAR TRANSISTOR DEVELOPMENT[a]

Transistor	Voltage, V	Current at gain = 10, A	Power handling, kW	Power dissipated at 75° C	Rise/fall, μsec	Storage, μsec
D60T	400 to 500	50	25	625 W	0.5	2.5
D7ST	400 to 500	100 to 150	50	2 kW	.75	4.0
D7 High Voltage	1000 to 1200	25 to 40	30	1.25 kW	.75	3.0
Augmented	800 to 1000	100	75	2.50 kW	.75	4.0

[a]Westinghouse Electric Corporation

TABLE II. – HIGH POWER DIODE DEVELOPMENT[a]

Diode	Voltage, V	Current, A	Power handling, kW	Thermal resistance junction to case, °C/W	Reverse recovery, μsec
PTC 900	1000	50	50	0.8	0.4 (from 50 A)
PTC 950	1000	150	150	.5	0.5 (from 150 A)

[a]Power Transistor Company

TABLE III – DC SOLID STATE RPC DEVELOPMENTS

RPC Status	Voltage V	Currents, A	Efficiency,	Trip Curve, (see Fig 4)
Space shuttle,* operational	28	3,5,7.5, 10,15,20	>95Δ	b
Flight ready* hybrid	120	5,30	99Δ	a,c
Engineering+ model	150	100	98.7Δ	a
Breadboard*	270/300	1,2	99Δ	a,c
Engineering+ model	300	35	99.5Δ	a
Engineering* models	200/400	25,50,80	>90Δ	a
Engineering+ models	800	10,35,65	99.5 to 99.7Δ	a
Engineering models	1000	15+,25*	99.6Δ	a
Engineering+ model	1200	6.5	99.7Δ	a

*Westinghouse Aerospace Electrical Division.
+NASA Lewis Research Center, In-House.

TABLE IV - HIGH VOLTAGE, HIGH POWER RPC DEVELOPMENTS

Voltage, V dc	Current, A	Power switch type
200-400	80	Electromechanical/Solid-State
200-400	50	Bipolar Transistor, D60T
150-800	100,35,10	MOSFET
800-1200	65,35,15,6.5	Thyristor (GTO)
1000	25	Thyristor (SCR)
1000	25	Bipolar Transistor, High Voltage D7 Type
1000	25	MOSFET's, Series-Parallel Combination

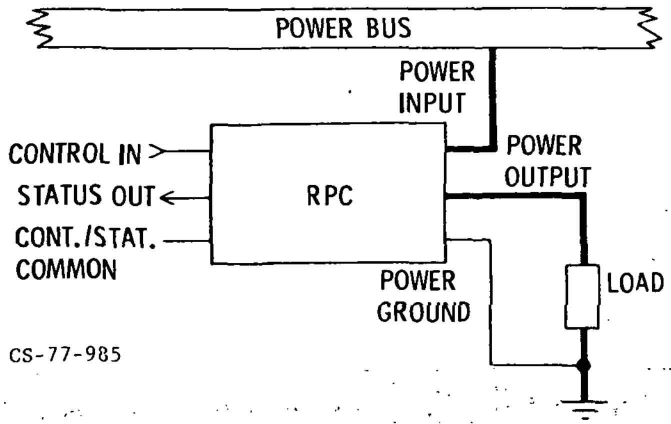
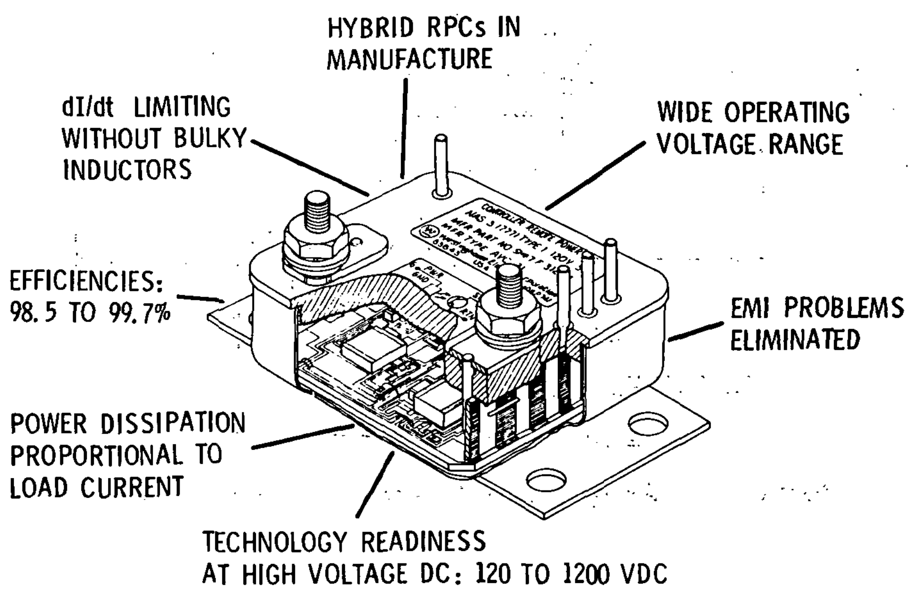


Figure 1. - Basic PRC in a typical application.



- COMPATIBLE WITH SOURCES, LOADS, COMPUTER CONTROL
- UNIVERSAL DESIGN APPLICABLE TO ANY VOLTAGE LEVEL
- SEVERAL AREAS OF POTENTIAL APPLICATION
- CONTROL AC POWER WITH SLIGHT MODIFICATIONS

Figure 2. - Outstanding features of NASA Lewis solid state RPC's.

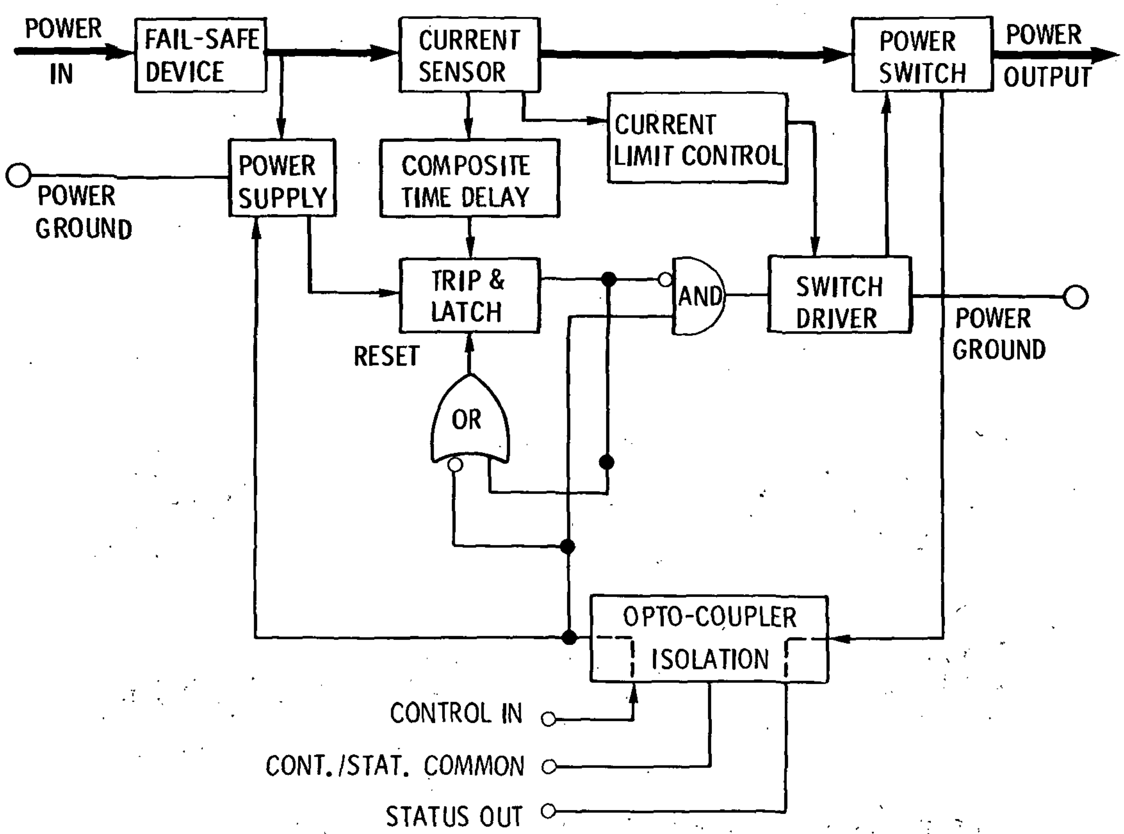


Figure 3. - Block diagram of an RPC showing each basic function.

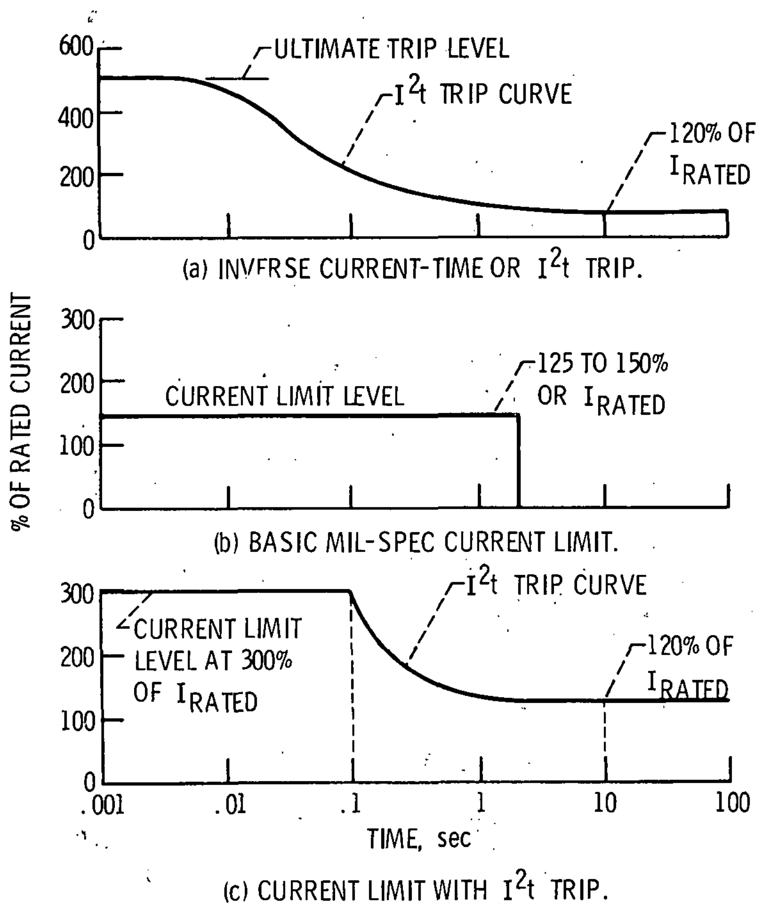


Figure 4. - Basic types of current protection in RPC's.

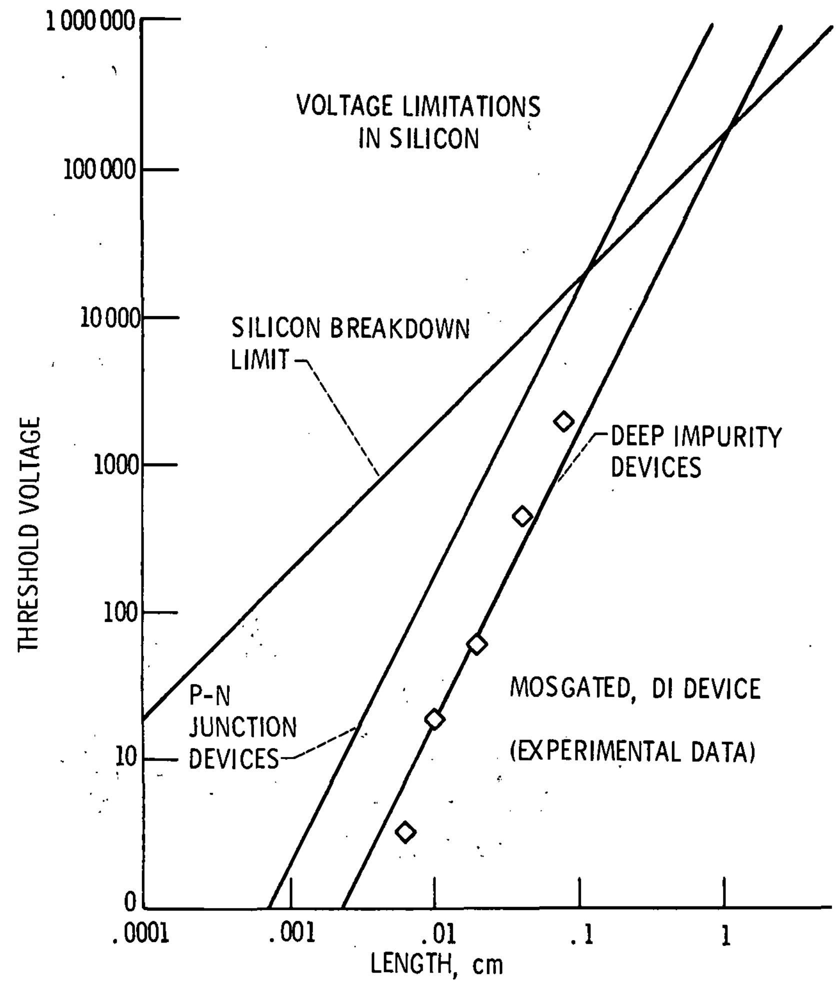


Figure 5. - High voltage capability of deep impurity devices compared to P-N junction devices.

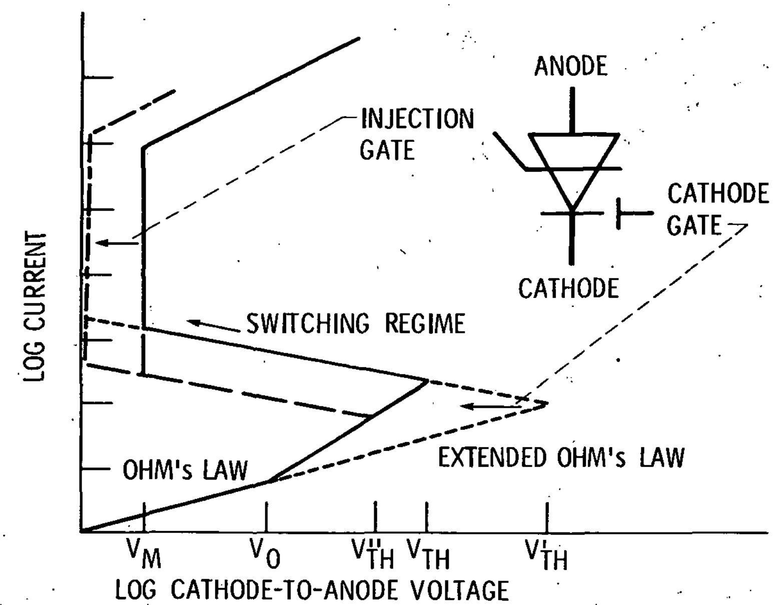


Figure 6. - Volt-ampere characteristic showing gating effects of $(D\ I)^2$ devices.

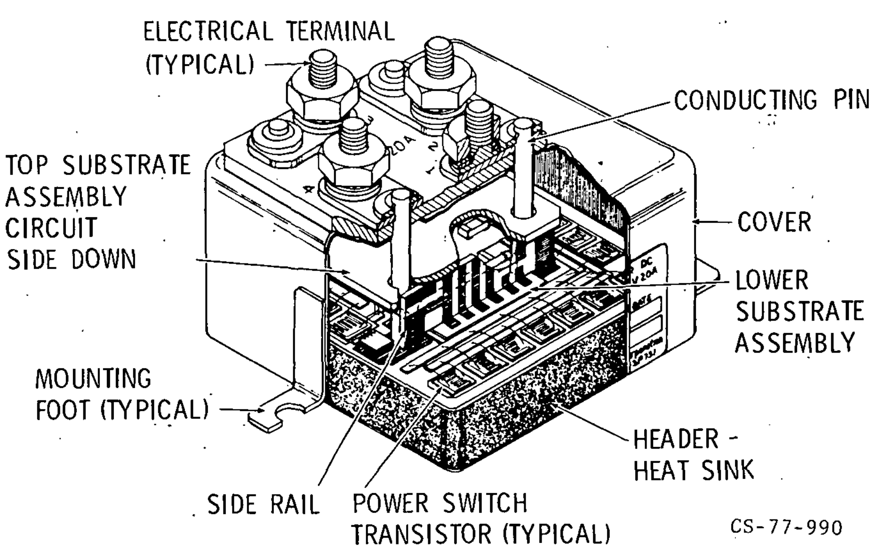


Figure 7. - Cutaway view of a Shuttle Orbiter 28 V dc remote power controller.

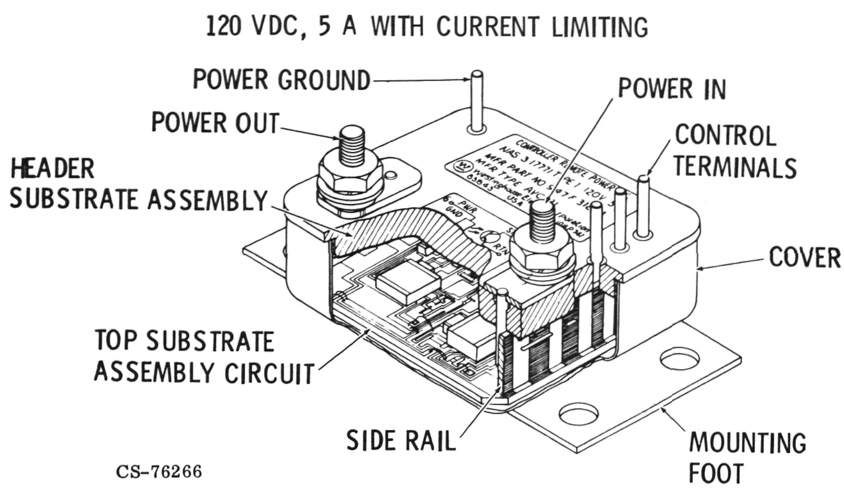


Figure 8. - Cutaway view of a packaged, hybrid 120 V dc remote power controller.

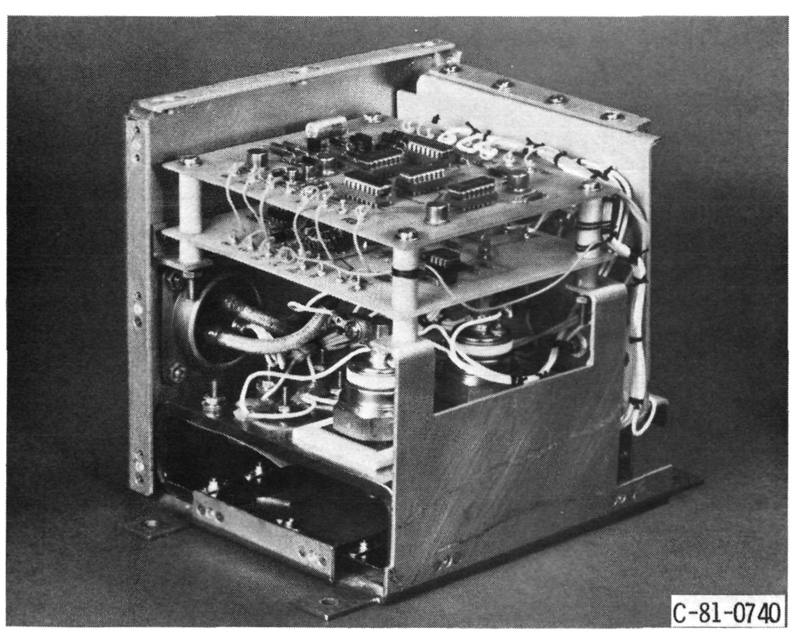


Figure 9. - A 400 V dc, 50 A engineering model of a bipolar RPC with cover removed.

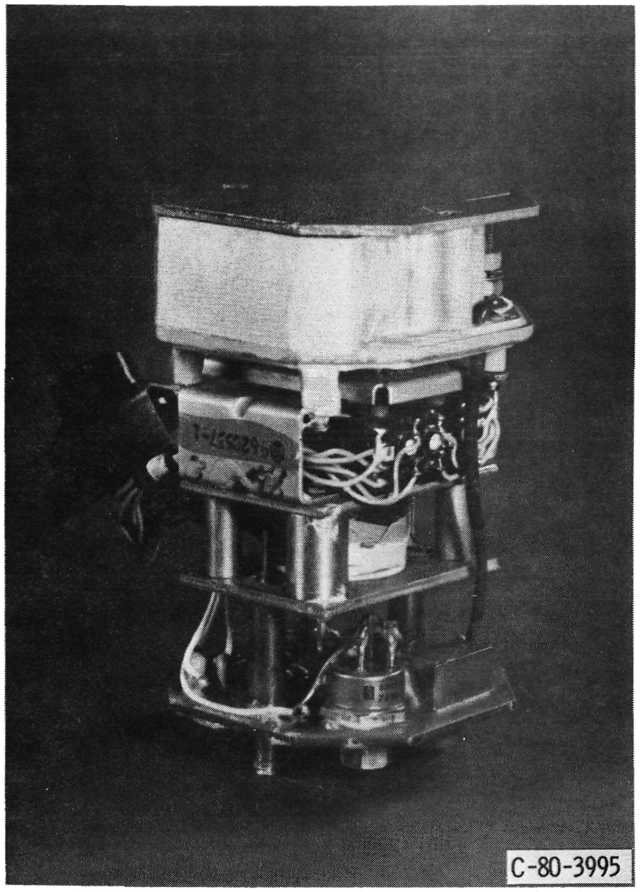


Figure 10. - A 400 V dc, 80 A hybrid electromechanical/
solid state circuit breaker with cover removed.

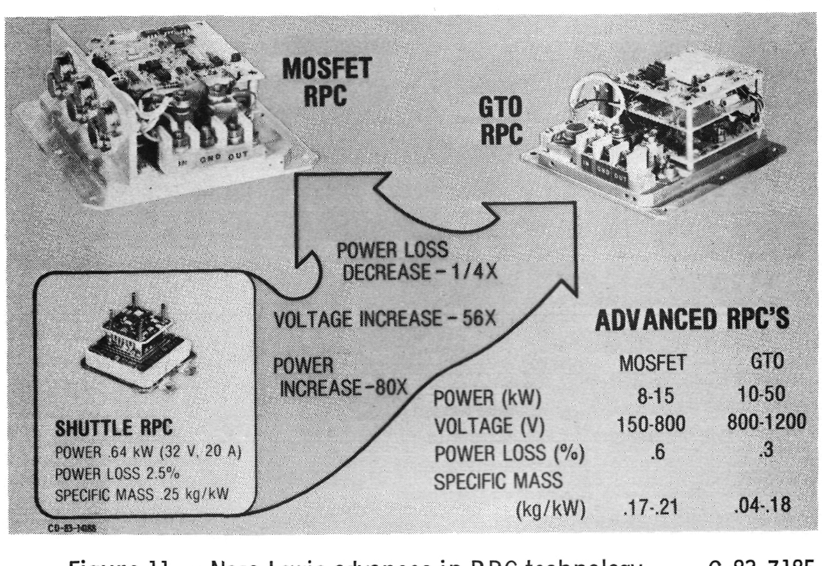


Figure 11. - Nasa Lewis advances in RPC technology. C-83-7185

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-83652		

4. Title and Subtitle

Advances in Solid State Switchgear Technology for Large Space Power Systems

5. Report Date

6. Performing Organization Code

506-55-72

7. Author(s)

Gale R. Sundberg

8. Performing Organization Report No.

E-2096

10. Work Unit No.

9. Performing Organization Name and Address

National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

11. Contract or Grant No.

13. Type of Report and Period Covered

Technical Memorandum

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Nineteenth Intersociety Energy Conversion Engineering Conference cosponsored by the ANS, ASME, SAE, IEEE, AIAA, ACS, and AIChE, San Francisco, California, August 19-24, 1984.

16. Abstract

NASA's Lewis Research Center has systemmatically pushed the development of high voltage solid state remote power controllers (RPC's) and the required semiconductor power switches to provide baseline technology for large, high power distribution systems in the Space Station, all Electric Airplane and other advanced aerospace applications. The technology of solid state RPC's has progressed from the development to the application stage at various voltage and power levels from a few hundred watts to 50 kWs. RPC's have been or are being developed for dc voltages from 28 to 1200 V and ac voltages of 115, 230, and 440 V at frequencies of 400 Hz to 20 kHz. This paper reviews the benefits and operation of solid state RPC's, and highlights several developments of NASA Lewis and other Government agencies to bring the RPC to technology readiness for future aerospace needs. Specific RPC's reviewed are the 28 V dc Space Shuttle units, three RPC types at 120 V dc, two at 270/300 V dc, two at 230 V ac and several high power RPC models at voltages up to 1200 V dc with current ratings up to 100 A. New technology programs to develop a new family of $(DI)^2$ semiconductor switches and 20 kHz, 440 V ac RPC's are also described.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Power controller; Space power systems; Spacecraft aircraft power; Solid state switchgear; Multiplexing and power controllers; Semiconductor switches	Unclassified - unlimited STAR Category 33

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified		

*For sale by the National Technical Information Service, Springfield, Virginia 22161